INTRODUCTION TO INVITED PRESENTATION

A number of specially appointed speakers were invited by the Pilot Study directors and by the meeting host. Papers or summaries of these presentations are given in the following in the chronological sequence in which they were presented at the meeting.

ENGINEERING FOR SUSTAINABLE DEVELOPMENT – AN OBLIGATORY SKILL OG THE FUTURE ENGINEER

Leo Alting
Professor
Department of Manufacturing Engineering and Management
Technical University of Denmark

Introduction

In the last few years it has become clear that our present industrial production and consumption culture is facing dramatic changes in the future due to:

- pollution and waste problems
- non-renewable resource consumption
- rapid growth in world population

The developing countries are fighting poverty and health problems and we have no choice but to support their struggle for economic growth, which is a prerequisite for a more stable world. Our best contribution is to develop a new sustainable industrial culture, which can be scaled up by a factor of 5 – 6 compared to the present level without creating unacceptable environmental and resource problems. The term sustainability appears more and more often in literature, public debates, as research issues, etc., but it is used in many different meanings. Broadly, the content of the term is determined by the different value criteria of the various interest groups around a company (share holders, suppliers, employees, local community, national and international community, political interest groups etc.). A closer study of these criteria results in the conclusion that the term sustainability includes the three main responsibilities:

- economic
- environmental
- social/societal

The economic responsibility has for many years been the dominating one, but in the last few years the environmental and the social/societal responsibilities are surfacing more and more to parallel the economic responsibility. These responsibilities are interlinked and all have a major influence on business opportunities.

Product Life Cycle Management

In the last few years the environmental focus in industry and legislation has shifted from the production processes to the products themselves throughout their entire life cycles (material extraction, material production, product production, usage and disposal). This is due to the fact that environmental impacts are created in all life cycle phases. Therefore, it is necessary both from an environmental and resource viewpoint as well as from a business viewpoint (manufacturer is responsible for the whole life cycle) to consider the product's life cycle in a holistic way with the aim of optimising the product performance. [1]

For this purpose a product life cycle management (PLCM) system should be adopted. Table 1 shows the main elements in a PLCM system and each company will have to – based on its own market and objectives – adopt these elements to its own management structure.

Table 1: Main elements in a PLCM system

Element	Purpose
A. Strategic management issue	Integration in the management structure
B. Life cycle assessment (LCA	Environmental focus; product development; documentation; internal & external communication
C. Life cycle engineering (LCE)	Definition of business objective, engineering methods and activities to support all product life cycle issues
D. Life cycle information (LCI)	Information flow and data to support life cycle management
E. Technological plat-forms	Monitoring technological developments

Each of the elements in the PLCM system will be discussed in the following.

A strategic management issue

It is a top management responsibility to ensure that the company has full awareness and knowledge of the products' life cycles and the consequences they have in all life cycle phases (environmental impacts, resource consumption). The company must clearly define its business objectives seen in relation to the products' life cycle and identify and describe the interaction and transfer between the "owners/partners" of the product in its life cycle phases. Introducing the PLCM will ensure that the company has all the necessary documentation of the products to be used internally as well as externally (interest groups, authorities, purchasing, marketing, etc.). It is the responsibility of the management to have full knowledge of the products and their consequences in all life cycle phases, and to show how they are dealing with these consequences.

Management focus on the subject will in itself create a better performance, but introduction of the necessary engineering methodologies/tools in the various company functions will provide more significant results.

It is necessary that the PLCM system is integrated in the overall company management system.

Life cycle assessment of products

As mentioned previously, the environmental focus has shifted from the manufacturing processes to the products themselves in their life cycles. For this purpose a methodology for assessing environmental impacts and resource consumption associated with the existence of products throughout their entire life cycles has been developed. It is called LCA (Life Cycle Assessment) and is a result of many years of international scientific development. The procedure is now being documented in the ISO standards:

- 14040 Principles and framework (1997)
- 14041 Goal and scope definition, inventory (1998)
- 14042 Life cycle impact assessment (draft, 1999)
- 14043 Life cycle interpretation (draft, 1999)

SETAC (The society of Environmental Toxicology and Chemistry) has made important contributions to the methodology development.

Based on the LCA the environmental focus for the product development can be established and design guidelines can be developed. LCA results can be used for various purposes both internally as well as externally.

Life cycle engineering

The term life cycle engineering is used to cover the activities, methods and tools that are used to develop the products for their entire life cycle. The main issues are:

- business objective
- life cycle design/design of life cycle

Business objectives (new opportunities)

It is very important that a company very clearly defines its business objectives. Here it is important to recognise that the physical part of many products is becoming a smaller and smaller part of the value chain in a product's life cycle. The service parts are increasing and the company must decide what is its business objective:

- the product
- the function/service of the product, i.e. maintain control of the life cycles
- after sales service, maintenance, online monitoring/maintenance, availability
- take back (to remanufacture)

The life time of the product is determined based on the objectives. It must be remembered that the product manufacturers are responsible for the impacts and consequences of the products in their entire life cycle, and therefore it must be investigated if this also means that it is advantageous to make usage and disposal part of the business. It is important that "ownership/responsibility" for the different parts of a life cycle is visible and that the partners having ownership optimise their collaboration.

New business objectives may arise seen in the product life cycle perspective and new technologies (micro/nano/sensor technology, telecommunication, supply chain management, etc.) may offer possibilities of realising these.

Life cycle design

When designing the product for all life cycle phases, it is important to optimise its total performance. Many issues/requirements have to be considered at the design stage, here mainly environmental and other life cycle related topics are mentioned. These topics must be balanced against all other product requirements.

Design for environment
Based on the life cycle assessment it is found what the problem is (effect potentials, main contributors, etc.). The designer can now look at what can be changed (materials, processes, functional elements, structure etc.) and what the environmental improvements are. Seen from the costs and the competitive position of the product, it must be decided which improvements should be implemented in the new product. Design rules may be developed based on the LCA results, for example energy reduction in usage, certain materials preferred, avoid following chemicals, etc.)

Design for X
Many other environmental and life cycle related issues have to be dealt with at the design stage and they can be listed as design for X. The following design issues (X) must be considered:

- distribution including packaging and transport
- installation (facility requirements, self-integration, plug & play function, etc.)
- maintenance (self-diagnosis, self-repair, online services, monitoring, teleservices, upgrading etc.)
- ease of manufacture (materials, processes, assembly etc.)
- remanufacture (reuse/repair, dismantling, recovery)
- take back (reuse in new products, upgrading, downgrading etc.)

These design considerations are very important and their contents depend on the type of product and on the defined business concept.

Product life cycle information
Information supply and communication among the different life cycle partners is an important aspect. Information has to be provided regarding design, materials, processes, components, service concepts, operating strategies, etc. A product state model must be developed accumulating all information about a product at the present time. This enables documentation of the product, service and operating manuals, usage information and disposal information.

For many products it will be of value at any life cycle state to have access to all data. Therefore questions about:
- product data management (design data, LCA data, production data, maintenance/repair data, etc.)
- database (structure/access)
- tele-/multimedia services (installation, plug & play, monitoring, online services, diagnosis, repair, etc.)

must be answered.

It could be considered to have the product itself carry the information in a chip. The coming sensor technology also enables easy data collection. It seems that the possibilities in the modern communication technology will provide new and advantageous solutions.

Technological developments/technology platforms
The technological development is progressing very fast, and it is mandatory that the company all the time closely monitors its technological platform to ensure the full potentials of its products.

Typical trends are:
- miniaturisation of products (saving energy and resources)
- micro-/nanotechnology (sensors, functional units)
- new materials and processes
- information technology
- networking
- virtual reality/virtual enterprise
- telecommunication
- plug & play software
- better energy efficiency in functional units
- communication capabilities in functional units
- production is becoming a project in the product life cycle

These trends show that many new possibilities are presented to the companies and it is important that the company always has an updated technology platform combined with an updated business objective.

Conclusion
The presentation indicates that the technical contribution to sustainability is closely linked to the life cycle perspective, and that large improvements compared to the present situation can be obtained.

Product life cycle management is an important tool that focuses the company's attention on the business objectives seen in the product life cycle perspective as well as on all activities that optimise the co-operation between the life cycle ”owners”.

Life cycle engineering covers methods and tools to support development, manufacture, usage and service and disposal of products to optimise business and sustainability.

References
[1] E. Westkämper, L. Alting & G. Arndt: ”Life Cycle Management and Assessment”, CIRP General Assembly, Sidney, Australia, August 2000

[2] H. Wenzel, M. Hauschild & L. Alting: ”Environmental Assessment of Products”, Kluwer, 1997

MEMBRANES IN PROCESS INTENSIFICATION AND CLEANER PRODUKTIONS

Enrico Drioli,
Institute on Membranes and Modelling of Chemical Reactors - CNR,
and Department of Chemical Engineering and Materials,
University of Calabria, Arcavacata di Rende (CS), Italy.

Introduction

Research progresses in Chemistry and Chemical Engineering have been made during the last decades with important contributions to the industrial development and to the quality of our life. An interesting case is related to the membrane science and technology continuous impact to innovative processes and products, particularly appropriate for a sustainable industrial growth. Reverse osmosis is today a well recognized basic unit operations, together with ultrafiltration, cross-flow microfiltration, nanofiltration, all pressure driven membrane processes. Already in 1992 more than 4 millions m3/day were the total capacity of RO desalination plants and in 1995 more than 180.000 m2 of ultrafiltration membranes were installed for the treatment of wheys and milk. In early 2000 the overall desalinated water produced worldwide by RO is overcoming the amount produced by thermal methods.

The concept of asymmetric structures realized with composite polymeric membranes made possible in the early 80s the separation of components from gas streams. Billions of cubic meters of pure gases are now produced via selective permeation in polymeric membranes.
The possibility of combining in a single step a molecular separation with a chemical conversion, realizing a membrane reactor, is offering new important opportunities for improving the efficiency of important productive cycles particularly in biotechnology and in the chemical industry. In September '97 five large petrochemical Companies made public their alliance for a research project devoted to the development of inorganic membranes to be used in the syngas production. This action came in parallel to the announcement of a 84 million dollars similar project, partly supported by the DOE in the USA, having Air Products and Chemical Inc. working together on the same objective. The availability of new high temperature resistant membranes and of new membrane operations as the membrane contactors is offering a important tool for the design of alternative production systems appropriate for a sustainable growth.

The basic properties of membranes operations make them ideal for a rationalization of the industrial productions; the fact they are athermal, (except membrane distillation) and don't involve phase changes or chemical additives, simple in their conception and in their operations, modular and easy in their scaling up, suggests significant reduction in energy consumption with a potential more rational utilization of raw materials and recovery and reuse of by-products. The membrane technologies, compared to those commonly used today, respond efficiently to the requirements of the so-called "process intensification", because they permit to bring drastic improvements in manufacturing and processing, substantially decreasing equipment-size/production-capacity-ratio, energy consumption and/or waste production and resulting in cheaper, sustainable technical solutions .
The potentialities of redesigning innovative integrated membrane processes in various industrial sectors characterized by low environmental impacts, low energy consumption and high quality of final products have been studied and in some cases realized industrially.

Interesting examples are in the dairy industry or in the pharmaceutical industry. Research projects are in progress, in the leather industry or in the agrofood industry based on the same concept.

Membrane Operations

It can be said that the existing membrane technology covers the widest spectrum of applications than any other single separation technology. In table 1 are summarized the most relevant processes and some examples of their mature applications.

Table 1: Applications of membranes operation in some industrial branches

Branch	Examples of matured implementations	Process
Chemistry	Concentration and recovery of substrates, catalyst's recycling, removal of organic components from water solutions, fractionation of hydrocarbons, crystal cleaning, recovery of cleaning agents, emulsion break-up, recovery and concentration of polymers, filtration of amines and glycols, purification and concentration of acids, purification of glycerin	RO, NF, UF, MF, PV, ED, DL
Petrochemistry	Fractionation of hydrocarbons, wastewater treatment, fuel dewatering, separation of azeotropes	PV, MD
Paper industry	Recovery of chemicals and reagents: pigments, chelating agents, emulsifiers, latex, defoaming agents, neutralization of wastewater	RO, NF, UF, MF
Textile industry	Recovery of oil finish, polyvinyl alcohol, latex, dyes and detergents	RO, NF, UF, MF
Leather industry	Recovery of tannin agents and chemicals from unhairing baths and tanning baths	RO, NF, UF, MF
Electronics	Preparing of ultra-pure water for flushing of integrated circuits, air filtration, water recycling	RO, NF, UF, MF
Metal industry	Regeneration of cooling emulsions for cutting, rolling drilling, etc, separation of condensates from compressors, neutralization of galvanic wastes, recovery of oils and greases from degreasing baths, concentration of washings with diluted electrophoretic paints	RO, NF, UF, MF
Transport	Removal of oil from washings after cleaning of transportation means and tanks	UF, MF
Energetic	Water softening, decarbonization, removal of radioisotopes	NF, RO, UF
Fuel	Manufacturing of ethanol from cellulose and starch, methane from agricultural and municipal wastes, hydrogen and hydrocarbons	UF, GS
Food industry	Recovery of proteins from animal and plant by-products, recovery of proteins from plants, soybeans, potato juice during starch manufacturing, desalting of vegetable dye, concentration of pectin and gelatin, cold sterilization of products	UF, MF
Sugar industry	Sugar refining, molasses removal, purification and concentration of cat and cane juice	RO, NF, UF
Beverages	Clarification of juices, syrups, wines spirits and liquors, concentration of fruit and vegetable juices, purification of organic acids, glucose and fructose. Cold sterilization of beer, wine and spirits	RO, NF,UF
Diary industry	Sterilization of milk, concentration of skim milk and whole milk during cheese making and powdered milk production, milk desalting, concentration of sweet and sour whey, manufacturing of protein concentrates from milk, recovery of lactose from whey	MF, UF, ED

Table 2
Sales of membranes & modules in various membrane processes

Membrane process	Sales 1998 [MioUS $]	Growth [% p.a.]
Dialysis	1,900	10
Microfiltration	900	8
Ultrafiltration	500	10
Reverse osmosis	400	10
Gas exchange	250	2
Gas separation	230	15
Electrodialysis	110	5
Electrolysis	70	5
Pervaporation	>10	?
Miscellaneous	30	10
Total	*4,400*	*>8*

Membrane operations shown their potentialities in molecular separations, clarifications, fractionations, concentrations, etc. both in liquid phase, gas phase, or in suspensions.
They cover practically all existing and requested unit operations used in process engineering. All the operations are modular, easy in their scale up and simple in their plant design. No moving parts; working totally unattended; lower cost; operational flexibility and when necessary, portability are other important aspects.
Several examples of successful applications of membrane technology as alternative to a traditional process may be mentioned.
The use of ion exchange membrane cells in chloro-soda production represent an interesting case study for analyzing the potentialities of membrane operations and one of the first success of their electrochemical application in minimizing environmental impact and energy consumption.
The success of this process suggested recently another interesting applications still based on cation transporting membranes as Nafion: the anhydrous electrolysis for chlorine recovery.

The recent development of nanofiltration and low pressure reverse osmosis membranes with interesting selectivity and fluxes, higher chemical and thermal resistance has been rapidly utilized for realizing innovative processes in various industrial sectors.
An interesting case studied in Italy is represented by the Iopamidol preparation in the pharmaceutical industry.
Also the integrated membrane processes proposed for the chromium recovery in the leather industry and the treatment of secondary textile effluents for their direct reuse, show efficient applications of nanofiltration and low pressure reverse osmosis operations.

In addition to the already mentioned membrane operations, gas separation, pervaporation and some others membrane processes which are showing in the last years significant potentialities for their application in various industrial areas must be cited; among these a class of membrane based unit operations (already known membrane systems and new ones) identified as membrane contactors, membrane bioreactors and catalytic membrane reactors.

APPROACHES TO CLEANER PRODUCTION IN ECONOMIES IN TRANSITION – THE RESULTS AND PERSPECTIVES OF THE CLEANER PRODUCTION CENTRES

Vladimir Dobes
Czech Cleaner Production Centre

Cleaner production is concept, which reflects general trends in environmental management:

- Increasingly clear limitation of environmental effectiveness and economic inefficiency of end of pipe solutions
- Increasing need for dematerialisation and increase of efficiency of processes, products and services
- Increasing need for avoidance of use of toxic materials
- More clear need for integrated and holistic approach to environmental protection.

These are trends, which are already starting to be reflected in new environmental policies and regulations worldwide (in Europe for example EC directive on Integrated Pollution Prevention and Control). There is also a broad understanding that these trends should be reflected in transformation of economies in transition and in restructuralisation of their industries as well.

Donor programs

The above mentioned trends together with high potential for reducing pollution through increased efficiency of industrial processes in economies in transition (CEEC´s) were one of the reasons why there were launched different donor programs in this field. Programs were focused on implementation of preventive environmental management in CEEC´s starting at beginning of nineties. These programs were at the beginning fully donor driven.

Practical implementation of preventive approach was promoted under different terms like cleaner production, pollution prevention, waste minimisation or clean technologies. We will utilise term cleaner production in this paper to refer to all these approaches and methodologies.

We can distinguish two basic approaches[1] in launching these programs:

1) **Demonstration of technology –** programs in field of direct assistance to concrete industrial branch and/or individual enterprise to solve concrete problem through technology transfer focused mainly on demonstration of hardware. This approach has impact mainly in innovation of equipment.
2) **Demonstration of methodology –** programs in field of capacity building with focus on training of trainers on demonstration projects in industry. This approach has impact mainly in developing local technical assistance, lecturing and managerial capacities.

The programs were normally mixture of these two approaches. They have created many concrete projects demonstrating double benefit of preventive environmental management in industrial enterprises (for example see enclosure, table 1).

Results and impacts

The programs were successful concerning their goals to demonstrate potential for cleaner production and to train domestic professionals in cleaner production (CP) methodology. There are being often discussed two problems related to these programs, which are interesting for our discussion.

The first is connected with reliability of presented results both in terms of environmental benefits and economic evaluation of measures. This was problem especially in cases in which the reports were developed by enterprise staff without reliable independent verification. However, we can see it also in cases in which international consultants developed reports without deeper questioning of data provided by enterprises.

We do not see this as a fundamental problem for two reasons:

- We have seen the not accurate presentation of results to vary on both sides (being higher or lower) and we estimate that the real theoretical results will be in sum corresponding with the presented ones. This difference is caused both by intentional and not intentional miscalculations and enabled by complexity of cleaner production measures. These measures have impact on different costs within and outside production process. We can state that many savings are omitted just because of poor identification of all aspects influenced within total costs assessment.
- There were already some improvements done in this area (for example verification of results through opposition of enterprise top management which has to pay percentage of savings from implemented measures and is therefore committed not to exaggerate the results).

The second problem, which we consider more serious, is problem of implementation of proposed measures, poor maintenance of implemented measures and lack of follow up actions. Many evaluation programs reported limited and or no follow up of activities implemented in enterprises after the external assistance is over. Enterprise managers perceived CP as tool, which is difficult to integrate into enterprise management and daily practice. This is especially perceived in situation in which enterprise face day by day survival problems (and this is normal situation of most of CEEC´s enterprises). There is a question if there are not the survival problems of these enterprises caused among others by lack of good strategical and preventive management and poor management of material and energy flows.

To understand better the second problem it is useful to make closer look on enterprises, which were successful in maintaining CP program ongoing after the external assistance was over. There were some common features like:

- management committed to strategical development of enterprise
- effort to involve employees into improvement of enterprise performance
- system approach to enterprise management and understanding importance of continuous improvement
- integration of CP with other activities within enterprise.

Concerning the question of general success of the donor programs we can conclude that the existing results proved and very well demonstrated that there is a high potential for double benefits from cleaner production measures in all different sizes and branches of industry.

On the other hand it become clear that it is much more difficult to achieve a broad spread of CP in respective countries than originally assumed. Training and demonstration does not lead to integration of CP into daily practice of industry and other stakeholders on its own.

Cleaner production centres

Some donor programs, which were aiming at broad integration of cleaner production into the industrial environmental management in target countries, introduced into their programs establishment of cleaner production centres (here we use term cleaner production also in its general meaning referring to all types of centres with different names).

The general purpose of these centres is not only to organise training and demonstration but also to go beyond demonstration and play key role in sustaining cleaner production programs in country after the international assistance is over.

We can distinguish two basic types of centres with understanding that the real centres are normally mixture of these two types:

1) Commercial consultant

The main functions of such a market driven centre are to provide information, training and technical assistance to industry and other stakeholders in such a way that this service recovers its costs and make it financially self sustaining. We can see that the successful centres, which have had this mission, are today operating as consultancy firms.

The main limitations here are:

- These centres are in order to survive in competition pushed by market to focus more and more on activities which are far from promotion of cleaner production.
- They are forced by market to keep their know-how for themselves to be able to sell it to their clients and therefore there is very limited or no multiplication effect.

2) Subsidised promoter

The main functions of such a mission driven centre beside basic promotional activities, training and technical assistance includes broad dissemination of the concept to different stakeholders, providing platform for cooperation of stakeholders, providing policy advice and facilitating establishment of financial mechanisms for investment needing cleaner production measures.

The main limitations here are:

- Donors and governments in CEEC´s are not committed for long-term financing of basic operation of any organisation even with very useful mission.

- Fully subsidised services are not so motivating both for providers and clients (there is a general perception in many CEEC´s that what is free of charge is not valuable).

Critical success factors
The centres, which survived and succeeded to keep their mission of focal point and source of know-how in field of cleaner production in their countries, are having features of both subsidised promoter but also of commercial consultant. The survival challenge for them is to keep revenue generating activities in field of cleaner production to be able to maintain their promotional functions. Other common strategy is to rise project based funding for the promotional activities.

There are some factors that we see critical for successful implementation of mission of cleaner production centres. They are illustrated on case of the Czech Cleaner Production Centre[2] in the enclosure.

1) *To build critical capacities within all stakeholder groups so that they can continue implementation of cleaner production on their own.*

Completion of this task is crucial for fulfilling the centres mission. We have to stress that the centre creates through this its own competitors. To cope with this challenge, the centre has to integrate the next success factor.

2) *To be source of new know how in field of cleaner production in the country.*

As the yesterday pilot activities are becoming standard ones and different stakeholders feel their ownership, centre can refrain from continuing in their direct implementation and has to come with something new what will be new interesting product to be spread.

This challenge is closely connected with experience that needs of enterprises are developing very quickly. The offer of cleaner production centre should follow this demand and changing conditions.

3) *To develop demand for cleaner production.*

This is the last and most complex success factor. We have already stressed that cleaner production programs in CEEC´s were donor driven at the beginning. We can see a slow-down of process of promotion of cleaner production in many CEEC´s due to a lack of domestic driving forces. Donors are withdrawing and new driving forces are not in place yet. These driving forces should be related to demand of local stakeholders, mainly governments and industry and should be reflected in relevant policies. For example investors or owners could play a driving role as well, however, there are not many precedents here yet.

There is a large set of tools, which can promote cleaner production to industry and create needed demand, which would utilise and enlarge cleaner production capacities developed within the initial programs. These tools can vary from soft information tools to compulsory systems, which work on principle of public access to benchmark information, or from market based economic tools to normative regulation based (for example on consideration of best available techniques within permitting system under Integrated Pollution Prevention and Control).

Commitment of governments is crucial here. Many have for example different schemes for support of end of pipe technologies. They can use cleaner production capacities for assessment of cleaner production potential before investing into end of pipe measures. The size of these measures and related investments would be significantly minimised as well as environmental risks.

The final goal concerning policies promoting cleaner production is to integrate them into sectoral policies. The "action ministries" are responsible for efficiency of their resorts and ministry of environment can play mainly facilitating and coordinating role here.

Conclusions

We can conclude that:

- Basic capacities in cleaner production were already developed or their development including establishment of cleaner production centres already started in many CEEC´s.
- CP programs have survival problems in many CEEC´s today as the driver of donor support is diminishing and domestic drivers are not in place yet.
- Governments and donors can play crucial role in establishment of self-sustainable cleaner production programs in CEEC´s through support of three critical factors mentioned above.

This support includes at the beginning building of domestic capacities, especially of consultants and lecturers. Institutionalisation through establishment of cleaner production centre proved to be very efficient. Centre plays role of an independent promoter and focal point, which brings different stakeholders together.

Development of new know how is very important as the next step. This can include for example:

- amendment of cleaner production methodologies, development of assessment tools etc.
- local authority cleaner production programs
- integration of cleaner production with quality and/or environmental management systems
- eco-design of products.

The third area of needed support is in field of governmental policies promoting cleaner production. This includes for example use of cleaner production for introduction of integrated pollution prevention and control or conditioning support for end of pipe measures by utilisation of preventive potential.

Cleaner production centres can develop their financial sustainability based on mix of products paid partly by clients and partly subsidised from public resources. This scheme often works only on a project base. This situation causes high uncertainty in centres strategical planning.

We can conclude that spread of cleaner production is an inevitable process considering the trends described at the very beginning of the paper. Cleaner production centres and other initiatives promoting preventive environmental management play important role in lowering our loses connected with slow adaptation of our processes, products and services to new demands.

Litterature

1) Rodhe, H.: Preventive environmental strategies in Eastern European industry, draft of doctoral dissertation. IIIEE, Lund University, 2000.
2) Christianova, A.: Industry and Cleaner Production – Making Business Profitable. Czech Cleaner production Centre, 2000.
3) Arbaciauskas, V.: Cleaner Production Centres in Central and Eastern Europe – Present situation and Future Directions, MSc Thesis. IIIEE, Lund University, 1998
4) Dobes, V.: Five Key Factors for Ensuring Sustainability of Cleaner production Programmes within a Country. Proceedings of Fourth European Roundtable on Cleaner Production, Oslo, 1997.
5) Kisch, P., Lindhqvist, T., Ryden, E.: Evaluation of UNIDO/UNEP National Cleaner Production Programme. IIIEE, Lund University, 1996.
6) OECD: Policy Statement on Environmental Management in Enterprises in CEEC/NIS. EAP Task Force, Paris, 1998.
7) Staniskis, J., Stasiskiene, Z.: CP Follow-up System in Lithuania. Proceedings of Sixth European Roundtable on Cleaner Production, Budapest, 1999.

CRITICAL SUCCESS FACTORS
EXAMPLE OF THE CZECH CLEANER PRODUCTION CENTRE

Vladimir Dobes
Czech Cleaner Production Centre

The Czech Cleaner production centre (CPC) was established in 1994 as an independent not for profit organisation within a framework of the Czech-Norwegian Cleaner Production Project. It broadened its activities within the five-year support of the UNIDO/UNEP Program for National Cleaner production Centres. CPC has headquarter in Prague and two branch offices in the Czech Republic. It also created large pool of domestic lecturers and consultants who are being involved in different cleaner production projects. Close cooperation with four universities secures training capacities and integration of CP into curricula. Here follows description of selected CPC activities related to the critical success factors presented within the paper.

Building capacities

In the first years of its existence the CPC has been focusing on technical assistance and training with implementation of concrete projects in industrial enterprises in the Czech Republic. Projects, which constituted a core part of CPC activities, were carried out in the form of long-term training courses consisting of lectures and the on-job training.

The results of these projects showed high potential for cleaner production in the Czech industry. We present summary of the main results here to support statements given within the paper in the

Table 1. We have to stress that the results does not include all benefits as they represent only the first annual gains and they do not include for example avoided investments to end-of pipe measures.

Environmental benefits (it is reduction of emissions, wastewaters, waste and dangerous waste) were achieved by both non-investment good housekeeping measures and by investments, which has typically a short to payback.

Tabel. 1: Summary of results of CP projects in the Czech Republic

Year	1993	1994	1995	1996	1997	1998
Number of long-term projects	1	1	2	4	1	4
Number of participating firms	7	6	10	23	7	21
Number of people trained	27	31	64	74	21	71
Environmental effects						
VOC emission reduced (Ton per year)	0	1982	151	335	10	237
Waste water reduced (Thousand m^3 per year)	0	5	7	907	3438	77
Non hazardous waste reduced (Ton per year)	51	9216	6481	413	30	630
Hazardous waste reduced (Ton per year)	8172	110	1335	595	198	574
Financial savings at firms (Million CZK per year)	9,7	30,5	43,9	103,9	20,5	39,1

Being resource of new know how

Regional projects

The most important new approach in dissemination of CP especially to small and medium size enterprises was development of projects in cooperation with municipalities, following model of successful program ECOPROFIT Graz and closely cooperating with Stenum Graz developer of the know-how.

Regional cleaner production projects make use of natural relationships among local enterprises, state administration and self-government and other interested parties. All the local stakeholders have common interest in the improving quality of environment in their city or region and in the increasing competitiveness of the local companies. Projects are carried out in form of several-months interactive course, in which 6-10 enterprises are involved.

After municipalities have seen the results of the projects there were committed to contribute financially to their follow up. This was important contribution to sustainability of there projects based on financing from local industry and municipality. A good example of fruitful co-operation can be seen, for instance, in the established relationship with the National Network of Healthy Towns.

Integration of CP and EMS
Another important new know-how was integration of CP and Environment Management Systems (EMS). The need for changes in management system to sustain CP program in enterprises was clear already after implementation of the first projects. This proven to be one of the differences in comparison with enterprises in countries where the concept of CP come from. They could integrate CP into functioning management system. However, we have found in our projects that most of enterprises need to develop such a system and CP methodology alone does not provide tool to do it.

EMS focuses on changes in the management system of enterprises and provides an appropriate framework for the long-term implementation of the CP programme within them. CP methodology focuses on the optimisation of the operating system and represents a tool for the continual improvement of the enterprises environmental performance – the very purpose of EMS implementation.

CPC started with integration of CP and EMS already in 1995 again with support of Stenum Graz within the UNIDO/UNEP program. The first enterprise with the intergraded CP/EMS system was certified against ISO 14001 in 1997. First regional CP/EMS project was implemented in 1998 in three enterprises in Zlín - in two municipal companies (Technical services and Water supplies and sewerage) and a small building company. In 1999 another projects started in the co-operation with Carl Bro (Denmark) in Rož nov following the EMAS standard.

The aim of CP demonstration projects is to show the benefits of CP and build professional teams within companies so that they will initiate a process of continuous improvement of CP. This aim is totally met only by those enterprises, which have integrated CP into their management system.

The principle objective of the CPC's new projects is to develop a CP methodology, which will integrate voluntary strategies in the environmental protection. A special attention will be paid to eco-design. The CPC will develop drafts of demonstration projects for individual production branches and will focus on the environmental impact of their activities.

International projects
CPC amended methodologies, which are being used in other countries to the Czech conditions. Acquired long-term experience and results of demonstration and training programmes in the Czech Republic were the basis for assistance in building the base for cleaner production in Croatia during the period of 1997-1999 and in Uzbekistan during 1997-1998. The project in Croatia was implemented in the framework of multilateral development assistance programme of the Czech Government under the UNIDO/UNEP NCPC Programme.

Developing demand for cleaner production.
There were some important milestones in development of demand for CP through governmental support in the Czech Republic. The first was establishment of CP Program at the State

Environmental Fund. The program supports investment needing CP measures through soft loans. CPC provides technical assistance to the fund within this program.

The Minister of Environment has signed the International Cleaner Production Declaration Within the High Level Meeting of NCPC in Prague in March 1999.

The Czech government in February 2000 adopted the Governmental Decree on Cleaner Production. Part of the Decree is the National Cleaner Production Programme. The Program provides guidelines for each governmental sector. The adoption of the program started integration of CP programs into development and implementation of policies of particular ministries.

The promotion of CP concept to governments is a process, which is for the time being in CEEC´s very much driven by concrete individuals. In case of the Czech Republic the achievements presented above were possible only because of strong commitment of concrete people at Ministry of Environmental of the Czech Republic.

COMPUTER AIDED MOLECULAR DESIGN PROBLEM FORMULATION AND SOLUTION: SOLVENT SELECTION AND SUBSTITUTION

*Rafiqul Gani & Peter M. Harper**
CAPEC, Department of Chemical Engineering
Technical University of Denmark
DK-2800 Lyngby, Denmark
** Current Address: IP-SOL, Gentofte, Denmark*

Abstract
A framework for the identification of environmentally benign and alternative solvents is presented. The methodology for solvent design and selection contains multiple phases: pre-design, design and post-design. A multi level CAMD method capable of generating a selection of candidates meeting the required specification without suffering from combinatorial explosion is presented and the entire framework is illustrated with a case study. The case study identifies alternative solvents for Oleic acid methyl ester as replacements for Ethyl ether and Chloroform.
Keywords: Solvent, substitution, CAMD, group contribution, pollution prevention, process synthesis

Introduction

One of the principal causes of pollution is the presence of a substance (or substances) in amounts higher than the allowed maximum in one or more streams released to the surroundings. Substitution of the polluting substance (or substances) by another that performs the same function in the process but is environmentally benign is one way of dealing with such environmental problems. Computer Aided Molecular Design, commonly known as CAMD, is well suited to solving this class of environmental problems (pollution prevention and/or treatment) because it can design/find the candidate replacements more efficiently than other search techniques.

Current applications of CAMD within this area have addressed environmental concerns and constraints using simple property estimation methods based on the group contribution approach. Also, most CAMD methodologies so far have designed relatively simple compounds by collecting fragments into group vectors (Mavrovouniotis (1998) lists a series of examples with references in his review of CAMD). While the generation of group vectors suits property prediction using group contribution approaches, the generated compound descriptions do not contain the additional structural details needed for the QSPR or QSAR methods, for example, a 3D representation of the molecular structure. It is therefore necessary to generate more detailed molecular descriptions in the CAMD algorithm. In this paper, a process systems engineering approach is applied to prevention and/or treatment of pollution through an integrated set of computer aided tools.

Solution methodology

The method of solution for the compound design and selection problem is an iterative process consisting of 3 phases: pre-design, design and post-design. The result of a successful completion of the algorithm is a list candidate molecules. All the candidates fulfil the property requirements set as design criteria.

Pre-design Phase

In the pre-design phase, the causes of pollution are identified together with the polluting substances and their undesirable properties. Once the causes have been identified it is necessary to formulate the strategy for solving (curing) the pollution problem. The routes of information leading to the identification include simulation, engineering knowledge, regulatory requirements, and observations of existing practices as well as changes in environmental policy.
CAMD can be used in the instances where the cure either involves the replacement of a process fluid or removal of a pollutant by using a solvent based separation technique. In the case of replacement solvents the general process equipment and operations have already been fixed and the substitute must function in all of them. If the search is aimed at finding a compound for use in a removal (cure) operation there are additional degrees of freedom since the separation method has not been fixed. In such cases different searches can be performed for the various feasible separation techniques. Determining the set of feasible separation techniques to consider is a separate sub-problem involving process design techniques.
After the problem has been identified and a solution strategy selected the pollution prevention or treatment problems are formulated in terms of desirable and undesirable properties. From an environmental point of view it is obvious that the properties of interest include environmentally related properties. It is however also necessary that the compound fulfils its operational role and there are therefore additional specifications that depend on the type(s) of operation(s) the compound is to take part in. A knowledge base is used to assist in the selection of the application-related properties and their values.

Design Phase

In the design phase the identification of compounds possessing the desired properties is performed by generating compounds matching the specifications. This is achieved by assembling building blocks. The evaluation of properties is performed using predictive techniques. By combining fragments to form molecules a wide range of compound can be generated and screened.

The methodology used for the generation approach is a multi-level approach. The computational complexity is controlled using two techniques: (a) Partitioning: by subdividing the generation procedure into several successive levels with a screening step between each level (allowing only the most promising candidates to progress to the next level) ensures that computational efficiency is maintained. (b) Feasibility: ensuring that only chemically feasible structures are generated not only improves the quality and ease of interpretation and analysis of the results but also eliminates the computational resources spent on false solutions. The method consists of four levels. The first two levels operate on molecular descriptions based on groups while the latter two rely on atomic representations (Harper, 2000). In outline form the individual levels has the following characteristics:

Level 1

In the first level, a traditional group contribution approach (generation of group vectors) is used with its corresponding property prediction methods. Group vectors are generated using a set of building blocks as input. The employed approach does not suffer from the so-called "combinatorial explosion" as it is controlled by rules regarding the feasibility of a compound consisting of a given set of groups (Harper, 2000). Only the candidate molecules fulfilling all the requirements are allowed to progress onto the next level.

Level 2

At the second level, corrective terms to the property predictions are introduced. These terms (so called second-order groups) are based on identifying substructures in molecules. At this level molecular structures are generated using the output from the first level (first-order description) as a starting point. The generation step of this level is a tree building process where all the possible legal combinations of the groups in each group vector is generated.

Level 3

In the third level, molecular structures from the lower levels are given a microscopic (atomic) representation by expanding the group representations in terms of the atoms each group is made up from. This can generate further structural variations. Furthermore the conversion into an atomic representation (including connectivity) enables the use of QSAR/QSPR methods as well as structural analysis methods. The possibility of using QSAR/QSPR methods and structural analysis significantly increases the applicability of CAMD in environmental applications since many environmental properties are only possible to estimate using such techniques and the available techniques are very specific with respect to the compound types they are applicable to. As an added benefit the structural analysis enables the re-description of the candidate compounds into other group contribution schemes thereby further broadening the range of properties that can be estimated as well as giving the opportunity to estimate the same properties using different methods for comparison.

Level 4
In the fourth level the atomic representations from level three are further refined to include the 3D position of the individual atoms. This conversion gives the opportunity to create further isomer variations (cis/trans and R/S) and is performed in a way that the output is compatible with most molecular modelling applications. Since property prediction using molecular modelling is a task difficult to automate the estimation and screening process is done interactively.

Post-Design Phase
In the post-design phase, the final selection from the generated list of feasible candidates is made. The final selection is done after careful analysis of the identified candidate molecules. Even though the results from the design phase fulfil the property requirements there are properties and criteria that are difficult to handle using automated prediction methods. Examples of such criteria and properties are: Availability, Price, Regulatory restrictions, Long term health effects, Detailed environmental fate and Process-wide behaviour.
The methods used to assess the additional considerations include external databases as well as other computational tools such as process simulators, environmental fate models and phase behaviour calculators. Which tools to use depend to a large extent on the type of application the compound is being designed for and the available range of applicable tools. After analysing the candidate compounds the final candidates must be selected for experimental testing or rigorous simulation. Regardless of the approach used for the selection of final candidates, the primary function of CAMD – identifying a set of candidates having the properties needed for a particular application - has been achieved.

Case study
The fatty acid ester "Oleic acid methyl ester" ((Z)-9-Octadecenoic acid, Methyl ester) is an important compound in a variety of applications, such as: intermediate for detergents, emulsifiers, wetting agents, stabilizers, textile treatment, plasticizers for duplicating inks, rubbers, waxes, biochemical research and as a chromatographic reference standard (NTP, 1999). Reported pure component solvents for Oleic acid methyl ester are: Diethyl ether and Chloroform (NTP, 1999) with Diethyl ether being reported as the best solvent. While both of the reported solvents are effective they also have unwanted properties. Diethyl ether is very volatile and flammable (including the risk of formation of explosive peroxides) and Chloroform is a suspected carcinogen. It is therefore desirable to identify alternative solvents that are safer and more environmentally benign than the above mentioned.

Pre-Design Phase
Determine a solvent having the following characteristics: (a) Liquid at (ambient) operating conditions. (b) Is non-aromatic and non-acidic (stability of ester). (c) Has low environmental impact and poses limited health and safety problems. (d) Is a good solvent for Oleic acid methyl ester.
The goals can be formulated as property constraints using the following values: Melting Point (T_m) < 280 K, Boiling Point (T_b) > 340 K.

The requirement of low environmental impact can only be addressed in part using property and molecular type constraints (non-aromatic compounds). The true environmental behaviour of a candidate compound must be assessed in the post-design phase as part of the analysis. However, it is possible to address some environmental considerations via a property constraint: (a) Compounds must be acyclic and must not contain Cl, Br, F, N or S. (b) Octanol/Water Partition coefficient (logP) < 2 (lower is better).
The determination of solvent ability towards Oleic acid methyl ester should ideally be calculated using an activity coefficient approach. However, since the solute in question is quite complex and very few predictive methods (e.g. UNIFAC, ASOG) are capable of handling large compounds the solubility requirement is addressed using a solubility parameter approach. Based on the theory of solubility parameters, a good solvent has a solubility parameter that is close to that of the solute. In the case of Oleic acid methyl ester the solubility parameter is 16.95 $(MPa)^{0.5}$. The solubility criteria than then be formulated as: $15.95\ (MPa)^{0.5} < \text{Solpar} < 17.95\ (MPa)^{0.5}$

Design Phase
Using the formulated CAMD problem with the added constraint of only allowing two functional groups in a compound (prevents generation of very complex and thereby expensive compounds) the following results are obtained:

- In level 1 of the CAMD procedure 2691 vectors of groups were created. After screening against the constraints 425 representations remained and were passed onto the next levels.
- 4593 molecular structures were created in level 2 based on the input from level 2. After screening 1351 candidates were passed on to level 3.
- No additional isomer forms were generated in level 3 and no screening was necessary (all properties had been handled in level 2).
- The final result from the CAMD approach was a total of 1351 compounds.

Stage 4
In order to select the prime candidates from the 1351 alternatives obtained from the CAMD solution an extensive analysis must be performed on the candidates. If only performance considerations are taken into account (i.e. how close the solubility parameter matches that of the solute) the following candidates are the most promising: Formic acid 2,3-dimethyl-butyl ester, 3-Ethoxy-2-methyl-butyraldehyde, 2-Ethoxy-3-methyl-butyraldehyde.
A more rigorous analysis has been performed but cannot be reproduced here due to the page limitation. The results are obtainable from the authors on request.

Conclusion
The algorithm outlined above provides an opportunity to solve pollution prevention and/or treatment problems in a more rigorous manner since widely used and more accurate property estimation methods can be used without sacrificing efficiency of the method of solution. This enables the user to find solutions that not only protects the environment but also has a high environmental benefit and/or process efficiency. The process systems engineering approach has combined aspects of computational chemistry, property prediction and process design for the solution of problems of current and future interest. A case study involving replacement of solvents with environmentally acceptable substances has been presented.

References

NTP, 1999 “Chemical Health & Safety Data”, National Toxicology Program, Online database.
Harper, P. M., 2000,”A Multi-Phase, Multi-Level Framework for Computer Aided Molecular Design”, Ph.D. Thesis, Dept. Chem. Eng., Tech. Univ of Denmark.
Mavrovouniotis, M.L., 1998, “Design of chemical compounds”, Computers and Chemical Engineering

THE FIRST STEP TOWARDS SUSTAINABLE BUSINESS PRACTICES: THE SB “DESIGN FOR ENVIRONMENT” TOOL KIT

Virginia L. Cunningham, Ph.D., *Director, David J. C. Constable, Ph.D., Manager, Alan D. Curzons, Manager, Environmental Product Stewardship; Corporate Environment and Safety, SmithKline Beecham, 2200 Renaissance Blvd., Suite 105, King of Prussia, Pennsylvania, 19406.*

Abstract

This presentation will provide a general overview of several initiatives we are undertaking in the area of “Design for Environment” and our efforts to determine what “Green Chemistry/Green Technology” mean for our company. We will describe how we are using Sustainability Metrics (Environmental), provide an in-depth review of our chemistries, and explain our use of Lifecycle Inventory and total cost assessment (TCA) methods to answer the very difficult question of what is really "Green." Our findings to date suggest that no single methodology in isolation will yield the "correct" or best result; rather, each different methodology informs the other and provides different viewpoints and potential answers to many difficult questions. A lack of standardized approaches to using these methodologies, and differences in impact valuation, present very clear challenges as to how best interpret data and make sustainable business decisions. Preliminary results will be presented to show the types of learnings that we are gaining as we have developed our sustainability metrics, pursued a detailed lifecycle inventory of a major drug product, evaluated our chemistries,and collaboratively developed a TCA tool.

Summary of presentation

The presentation gave a brief overview of sustainable business practice at SmithKline Beecham with focus on the Design for Environmental Tool Kit. The most effective ways to integrate sustainable business practice are considered to be

- Life Cycle Assessment
- Total Cost Assessment and
- Green Chemistry

How do you weave the sustainability into an every day business practice in a multinational business? First of all, if you are not keeping score you are not acting. There a very different

Figure 1. Eco-Efficiency Metrics

paradigms for measuring. One of these are set by the World business Council as shown in figure 1. However, what we stress is that sustainable metrics are not environmental performance metrics or eco- efficiency metrics. Under the auspices of American Institute of Chemical Engineers' Center for Waste Reduction Technologies, SmithKline Beecham together with other large pharmaceutical companies and chemical companies has tried to define what sustainable metrics means and what will be useful to the companies. One approach is to combine efficiency type metrics with economic information. It is important to pick the right set of metrics. SB is working on moving the company from environmental performance metrics to sustainability metrics, see figure 2.

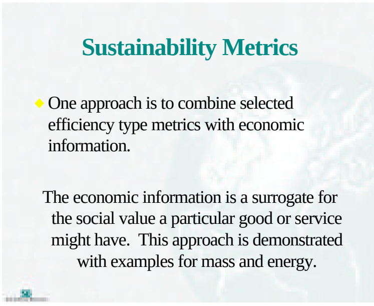

Figure 2. Sustainable Metrics

Why does SB want to design for an Environment Tool Kit? In essence, because of the nature of our industry, it is very difficult to make substitute changes after a product is in production. The company is highly regulated and if you make changes in the profile of i.e. a pharmaceutical product you have to re-do clinical trials, which is very costly.
So if you want to make changes you have to do it when developing the product. We want a tool that can be used by the chemical engineers as they are making their choices and highlighting issues as early as possible, so you have the time to come up with appropriate solutions.

Life Cycle Assessment
Beside metrics we focus on whole idea of LCA, Total Cost Assessment and Green Chemistry. However, the controversial issue of LCA is the evaluation of impacts. We know what the impacts are, but how the impacts are weighted is still a controversial question. At SB we are involved with LCA in two areas

- Packing
- Pharmaceutical R&D

Packing is in large part driven because of the European Packing Directive. Every new concept of packing has to go through a life cycle assessment as part of the decision process and an easy accessible tool is provided on the SB Intranet Site, see figure 3 and 4.

Figure 3. SB Intranet Site

Figure 4. Packaging Development

For pharmaceuticals R&D work has been ongoing for a couple of years. The goal is to develop a framework tool for the scientist, much like the packaging tool. The task of getting life cycle data is quite huge. We started out by contacting our suppliers to see if data was available but only a couple of companies were actually able to deliver data. SB is working with professor Michael Overcash, North Carolina State University to develop a database essentially from scratch. At present there is approx. 300 chemicals in the database whereof about 125 are SBs. A Life Cycle Inventory-model showed that solvents in the products cause major environmental impacts, and one of the first actions at SB was to develop a Solvent Selection Guide.

Total Cost Assessment

Another tool that is considered useful is Total Cost Assessment, which translates the impacts into dollars. We believe that we can sell this concept easier in the business environment. People can see dollars, whereas it is hard to see global warming or eutrophication, when they do not even know what that means. Dollars you can understand.

A prototype tool for total cost assessment has been developed and is being tested in different companies, but there are still a lot of gaps.

Green chemistry

With regard to Green chemistry, complex molecules, complex chemistry, and regulations constrain pharmaceutical companies more than perhaps other industries. Up till now focus has been on waste loads which mostly means waste minimization that is not the right driver for sustainability. To develop green chemistry in context with sustainability, we looked at all the chemistry that we could find in the company for the last 10 years. We ended up with over 200 examples from 35 products. These were categorized. 25 chemicals represented 80% of all the chemicals that we use. Now we are evaluating each of these for their greenness. The goal is to come up with metrics similar to the sustainability metrics.

BIOLOGICAL CONTROL OF MICROBIAL GROWTH IN THE PROCESS WATEROF MOULDED PAPER PULP PRODUCTION - AVOIDING THE USE OF BIOCIDES

Gert Holm Kristensen and Martin Andersen
DHI - Water & Environment,
Agern Alle 11, DK 2970 Denmark

Abstract
Among the large water consuming industries are the paper mills, including paper mills based on recycled paper. Recycling of the white water results in a build-up of components released from the recycled paper and components added during the production. One of the serious problems encountered when decreasing the water consumption through increased recycling, is caused by the high concentrations in organics, COD, released from the paper. A major part of the COD is easily degradable by microorganisms, which give rise to excessive microbial growth in the water system, if not controlled. Such excessive growth of biomass in the water and production system may lead to various problems and nuisances, like foul smell, corrosion, clogging, reduced product quality, reduced hygienic quality of the working environment.

As part of a large Danish project on industrial water management, CEVI, various scenaria for optimising the water management at the recycled paper factories are being evaluated, aiming at avoiding the addition of biocides for controlling the biological growth. The most promising scenaria are being investigated experimentally. The scenaria comprise: avoiding the biofilm growth by addition of dispergents; aerobic removal of organics; anaerobic/aerobic removal of organics; membrane filtration for removal of organics and subsequent anaerobic digestion of the organics in the concentrate; The scenario evaluation activities include model simulations and technical/economic/environmental evaluations.

Introduction
As water is getting a limiting resource water reuse has become more and more attractive in the water consuming industries. Among the large water consuming industries are the paper mills including paper mills using recycled paper. Recycling of the white water has already been implemented in many mills, and the water consumption lowered significantly and even closed in some cases. Closed water circuits have until now in most cases required large dosage of biocides to control growth, and thereby avoid corrosion, bad odours and deterioration of the paper quality produced.

Attempts to control the growth of microorganisms in the water system have been described in literature. Some of these efforts have focused on optimizing the water circuit around the stock preparation and the paper machine, while others focus on removal of the substrate and microorganisms.

Biological treatment of the effluent wastewater from paper mills is well known and described in the literature. Möbius and Cordes-Tolle (1994) review the existing knowledge and best available technology and discuss the possibilities of further reuse of water in the paper industry by using biologically treated effluent in the process.

The most common way of controlling the microbial growth today is the addition of various biocides. However, due to the harmful impacts of biocides on the environment, the growth control by biocides addition is not an attractive long-term solution and new control measures are being investigated.

To control the biological growth in the water circuit without using biocides, different strategies can be used. In table 1 the different mechanistic ways to control the growth and possible technologies, which can be applied, are described.

Table 1. Control of microbiological growth: Mechanisms and Technologies

Mechanism	Technology
Removal of the substrate	Biological treatment, Membrane filtration
Removal of the microorganisms	Membrane filtration,
Killing of the microorganisms	UV, Ozone, Biocides

The increased reuse of paper leads to a steadily deteriorating quality of the raw material and an increased content of small organic molecules like volatile fatty acids. These organics are an excellent substrate for bacterial growth, and if sufficient nutrients are present the growth will be difficult to control. Removal of the substrate can be done by controlled biological growth in an aerobic or anaerobic stage or by membrane filtration.

Removal of the microorganisms will solve the problems with the suspended bacteria but biofilms will still develop in pipes and tanks and the effect will therefore be local. Killing of the bacteria by ozone or UV has the same limitations. It will only be efficient locally, while growth still is possible in pipes and tanks. The best solution thus seems to be removal of the growth potential from the water through removal of the easily degradable organics.

Hartmann waste paper processing mill

Hartmann produces egg trays and other products of moulded paper from recycled newspapers. The factory has implemented different water recycling methods to reduce the water consumption. The white paper from the paper machines is flotated before reuse for pulp preparation and at the paper machines, partly for adjustment of the consistency of the pulp and partly for spray water at the machines. The spray water requires low suspended solids content. A side stream of the flotated white water is sand filtrated and reused for special technical purposes. With the implemented water reuse technologies, the water consumption has been reduced to around 5-10 m^3/ton of the product. The cleaning methods implemented until now have focused on removal of fibres and other suspended solids leaving dissolved organics and inorganic substances unaffected.

The factory is now facing two major limits for further recycling:

– The content of dissolved organic matter has reached a level where growth in the water system is getting difficult to control.

– The concentration of different ions is reaching a level where precipitation in pipes and nozzles may cause problems.

The system consists of 4 stock preparation pulping units and 10 paper machines for moulded paper production. Part of the pulp is dewatered at a belt filter press before the paper machines to establish water recirculation around the stock preparation and water recirculation around the paper machines. A simplified flow sheet of the production and recirculating white paper is presented in figure 1.

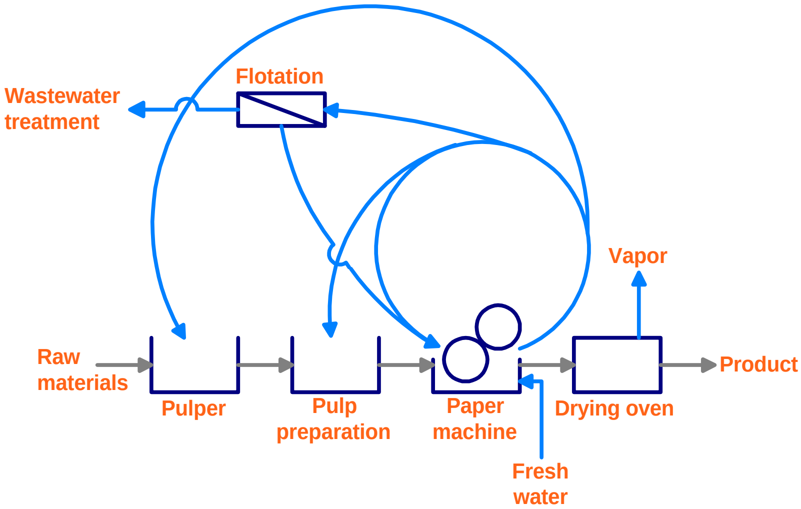

Figure. 1 Flow-scheme for production of moulded paper.

Scenaria for avoiding biocide addition to white water system
A system analysis has revealed three conceptually different scenaria for control of the biofilm growth potential in the white water system, without the addition of biocides. The scenaria are shown in Figs. 1, 2, and 3.

In the first scenario the growth potential in the white water system is reduced by biological removal of the easily degradable organics in the white water.

In scenario 2, the biological growth is suppressed by removal of the organics in the white water by membrane filtration. The organics in the concentrate are utilised by biogas formation through anaerobic fementation.

In the third scenario the pulp is washed and two water loops are introduced: one around the pulper and one around the paper machine. The organics are removed from the water loop around the pulper.

The three scenaria are subjects to technical/economic/environmental evaluations. Mathematical simulations and experimental investigations are applied in order to identify and design the optimal concept for bio-growth control without the addition of biocides.

Besides the above mentioned scenaria it is also being part of the study to investigate the substitution of biocides with the addition of dispergents to the process water system. The mechanism involved is that microbiological growth is allowed to take place, but formation of the problem causing biofilm is avoided through the addition of components affecting the tendency of the microorganisms to adhere to surfaces.

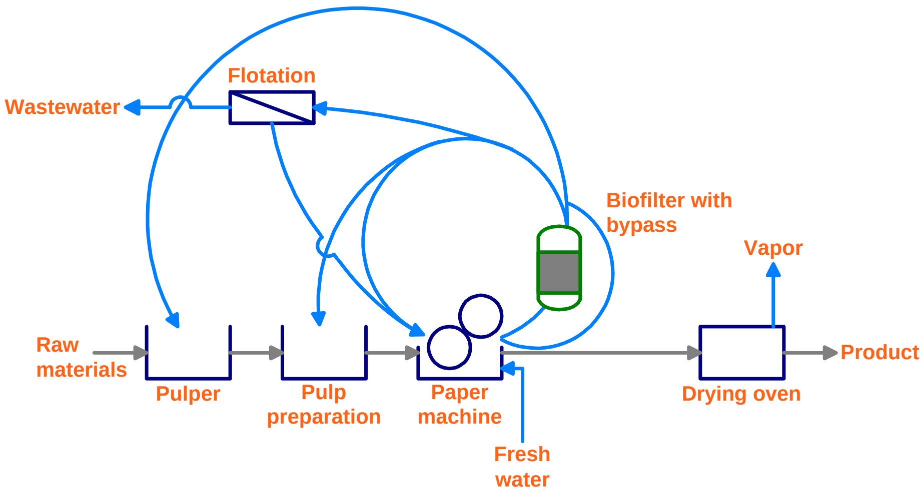

Figure 2. Scenario 1. Removal of organics by biological treatment at white water loop.

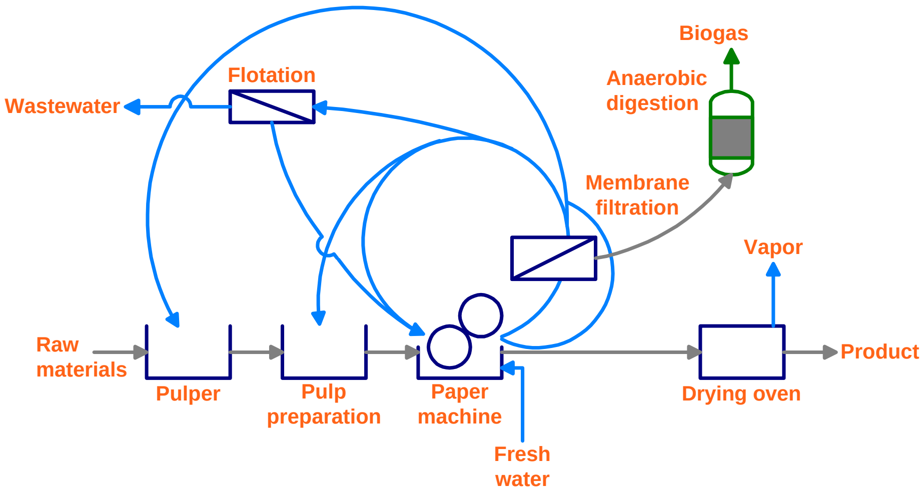

Figure 3. Scenario 2. Removal of organics by membrane treatment at white water loop.

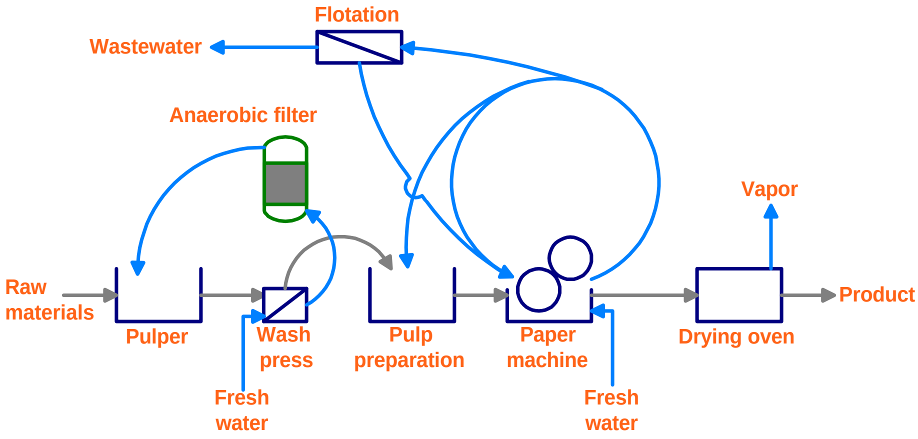

Figure 4. Scenario 3. Removal of organics by biological (anaerobic) treatment at pulper water loop.

Treatment and characterization of white water

Pilot plant experiments with bio-filtration at the Hartmann factory in Tonder (Jepsen et al., 1996) have shown that it is possible to remove efficiently the easily degradable organics, thereby reducing the growth potential in the process water system. Very high loads have been applied to the biofilter due to the favourable growth conditions: easily degradable organics and a high process temperature. Dosing of nutrients, nitrogen and phosphorus, to the biofilter were needed. Effective control of the nutrient dosage was essential, as excess nutrients were recycled with the treated water, resulting in an enhanced growth potential in the water system.

Oxygen utilization rate (OUR) measurements have been used to characterize the degradability of the COD in the white water before and after biological treatment. OUR measurements give the basis for calculating the different fractions of the carbon; easily degradable, easily hydrolysable, and slowly degradable (Kristensen *et al*., 1992). From the OUR experiments it can be calculated that about half of the COD content in the white water can be removed in the biofilter. The rest of the carbon will only cause minor problems with growth because it has to be hydrolyzed before the microorganisms can utilize it.

Experiments with membrane filtration have shown, that it is feasible to apply this technology on the white water (Knudsen et al., 1996). The experimental work was undertaken with ultra filtration and further investigations are needed to explore the possibilities for reverse osmosis.

Before implementing new technology in the paper mill it is important to evaluate possible new barriers for extended water reuse. At Hartmann the content of inorganic ions especially sulphate and calcium may cause problems with precipitation. To reduce the water consumption further it may be necessary to substitute aluminium sulphate with other chemicals in the production.

Conclusions

From pilot plant experiments it was found that the biological filtration was an efficient way of reducing the content of easily degradable organics; thereby reducing the growth potential in the process water system.

Membrane filtration by reverse osmosis is another possible way of reducing the content of easily organics in the white water. However, long-term experiments need to be undertaken if the technical/economical/environmental evaluation points at this scenario as being attractive.

Separating the process water system into two systems; one system around the pulper and one system around the paper machine; might be an attractive solution for removing the organics released from the raw materials. The biological processes applied to remove the organics from the pulper water loop are well known and process wise the scenario is considered feasible.

The mathematical simulation is considered a valuable tool for optimisation of each scenario, once the scenario is identified.

Large scale experiments are recommended with all scenarios before full scale imlementation, in order to evaluate/quantify the impact; i.e. the biofilm growth control; on the process water system.

References

Jepsen S.E., G.H. Kristensen, H. Wenzel, H.H. Knudsen, A.L. Mortensen, U. Ringbæk (1996). Control of Microbiological Growth in Recycling Water in a Waste Paper Processing Mill. *Wat. Sci.Tech.* Vol 34, No.10, pp 105-112.

Knudsen, H.H., H. Wenzel, J. Wagner, S.E. Jepsen, G.H. Kristensen, A.L. Mortensen, U. Ringbaek (1996). Membrane separation processes in recycling paper processing mills. Presented at 5. IAWQ Symp. on Forest Industry Waste Waters. Vancouver, Canada, 10-13 June 1996.

Kristensen, G. Holm, P. Elberg Jørgensen and M. Henze (1992). Characterization of functional microorganism groups and substrate in activated sludge and wastewater by AUR, NUR and OUR. Wat. Sci. Tech. Vol 25 No 6, pp 43-57.

Möbius C.H. and M. Cordes-Trolle (1994). Production Dependant Specific Data of Paper Mill Wastewater: Information for Treatment and Reuse. *Wat. Sci.Tech.* Vol 30, No.3, pp 193-198.

ENVIRONMENTAL LIFE CYCLE ASSESSMENT OF ALTERNATIVE SCENARIOS FOR BIOLOGICAL CONTROL OF MICROBIAL GROWTH IN THE PROCESS WATER OF MOULDED PULP PRODUCTION

Henrik Wenzel[1] and Nilgun Kiran[2]
[1]*Technical University of Denmark, Denmark, e-mail: wenzel@ipt.dtu.dk*
[2]*TUBITAK-Marmara Research Centre. e-mail: kiran@mam.gov.tr*

Abstract
This paper comprises the environmental feasibility study of 7 different scenarios for biological control of microbial growth in the process water of moulded pulp production at Brdr. Hartmann A/S. The study is a simplified Life Cycle Assessment of the environmental consequences of each scenario compared to the present operation as reference. The Life Cycle Assessment comprises material and energy flows within the cradle-to-grave system of all equipment to be installed in the scenarios in question. The assessment proves an in-line anaerobic treatment to be environmentally preferable and shows that the energy flows in the operation of the biological plants are key to the environmental profile of the scenario.

1. Introduction

The Danish moulded pulp producer Brdr. Hartmann A/S continuously strives to improve the environmental performance of their processes and the environmental profile of their products. The company produces moulded pulp products, mainly egg trays, based on waste paper. A high degree water reuse is implemented. Like for all paper mills of this kind, control of microorganisms in the water system is a necessity, and like other paper mills, Hartmann uses biocides. Hartmann seeks, however, alternative ways of controlling the microbial growth in the system in order to avoid the use of biocides, and the feasibility of biological control is being investigated. Several scenarios for
aerobic and anaerobic in-line treatment of the process water is being studied, and their technical, economic and environmental feasibility assessed.

As the means of studying the environmental feasibility of a scenario, Hartmann uses Life Cycle Assessments and this was the case also for studying these water reuse scenarios. Life Cycle Assessment is, however, a time consuming discipline, and in this case, a simplified approach was used, developed by Wenzel et al. (1999).

1.1 The Concept of Life Cycle Assessment

Environmental Life Cycle Assessment (LCA) is a tool for assessing the environmental impacts of a product, or more precisely, of a product system required for providing a particular unit of function. The term product system is taken to mean the product throughout its entire life-cycle, from cradle to grave, in terms of all the economic processes involved. The term economic process – employed as the converse of environmental process – refers to any kind of process producing an economically valuable service such as e.g. a manufacturing process, a transportation or a waste handling. LCA takes as its starting point the service provided by a product system and, in principle, takes into account as far as possible all the environmental impacts of all the processes needed to provide this service – from resource extraction, through materials production and processing, consumption or use of the product, to waste processing of the disposed product.

LCA is not one specific method, but rather a framework for a systematic and comprehensive environmental assessment of goods and services. Traditionally, only detailed, quantitative LCAs have been accepted as "real" Life Cycle Assessments, but both on the methodology side and in practical applications more simple approaches are being developed and used. Three types of LCA approaches can be identified (Christiansen ed., 1999):

(i) **Life Cycle Thinking** is commonly used term for qualitative discussion to identify the stages of the life cycle and/or the potential environmental impacts of significance e.g. for use in a design brief or in an introductory discussion of policy measures. The greatest benefit is that it opens for a holistic view and helps addressing potentially essential implications of a given decision in a wider scope. Life Cycle Thinking is mainly qualitative and does not support addressing proportions.

ii) **Simplified LCA** is an application of the LCA methodology for a comprehensive screening assessment, i.e. covering the whole life cycle but in an overall manner without a great degree of detail e.g. using generic data (qualitative and/or quantitative), standard modules for transportation or energy production – followed by a simplified assessment, i.e. focusing on the most important environmental aspects.

iii) **Detailed LCA** is an application of the LCA methodology for a detailed, quantitative life cycle inventory analysis and life cycle impact assessment of all important environmental aspects of the product system.

1.2 Simplified Life Cycle Assessment

LCA is commonly perceived as being complex, time consuming and expensive, and many potential users of LCA are put off as a result of that. However, a "full" LCA, if such a thing exists, may not be required. In many cases, all that is needed is a simplified, cost effective LCA.

Simplification, however, may affect the accuracy and reliability of the results of the LCA. This may make the LCA results of little value. What is needed is an LCA that involves less cost, time and effort, yet provides answers/results that meet the goal of the LCA with a sufficient accuracy. Thus, the aim of simplification must be to identify those areas within the LCA, which can be omitted or simplified without jeopardising reliability.

A simplified LCA should cover three steps, which are iteratively linked (Christiansen ed., 1999):

i) **Screening**: Identifying those parts of the system or of the elementary flows that are either important or have data gaps

ii) **Simplifying**: Using the findings of the screening and focusing the work on the important parts of the system or of the elementary flows. Doing the LCA on these parts.

iii) **Assessing reliability**: Checking that simplifying does not significantly reduce the reliability of the overall result.

In all cases, an LCA study covers *four* interrelated phases named 1) Goal and Scope Definition, 2) Life Cycle Inventory Analysis, 3) Life Cycle Impact Assessment and 4) Life Cycle Interpretation. The goal and scope definition should not be simplified, but the other phases can be simplified by applying methods of screening, simplifying and assessing reliability.

Goal and Scope Definition
All LCA studies should start with a goal and scope definition. The goal and scope definition should state unambiguously the intended application, including the reasons for carrying out the study and the intended audience, i.e. to whom the results of the study are intended to be communicated. Because LCA is an iterative process, the scope of the study may be altered during the study as the insight increases and/or additional information is collected.

Inventory Analysis
In order to develop *effective simplification methods*, it is obvious to address the *Life Cycle Inventory Analysis,* which is typically the most time consuming phase, with the greatest potential for savings. The Life Cycle Inventory Analysis phase offers the greatest scope for simplifying due to its data intensive nature. The majority of methods to simplify the life cycle inventory analysis are therefore aimed at reducing the data collection requirement.

In comparative LCA studies, it is important to ensure that the system boundaries, data quality and data sources are as similar as possible for the product systems being compared, otherwise an incorrect result is likely to be produced. The essential topics that have to be taken into consideration during simplification are categorised below:

i) Data Priorities: The availability of data is a common problem in LCA. One, therefore, often has to accept data that are not highly accurate. Some methods of dealing with data gaps are given below with a descending order of accuracy:

- Use calculated/ measured data
- Use best available data from a similar product or process
- Make estimates, e.g. educated guesses, estimated data from design and engineering figures or from past experience and process knowledge.
- Use data from regulatory requirements/legislative limits
- Use qualitative data, e.g. as often done in eco-labelling.

Since primary data that is specific to the product system under consideration is rarely available and necessitates very extensive data collection, secondary or generic data sources can be used i.e. from literature or databases.

The problems that arise when using secondary data sources are mainly due to the poor transparency of the data quality i.e. on how well the data represent the process/system in question. Also, as final results are typically published, it is difficult to determine the relative environmental impacts of the various stages of the life cycle and the contributions made by energy generation, transportation, waste management etc. Difficulties also occur in comparing different secondary data sources due to variations in data quality and system boundaries. In addition, secondary data may not be representative of the whole industry, particularly if the data is based on only a small sample of the industry.

ii) Use of a limited number of inputs and outputs: Ideally, data should be collected on all the environmental inputs and outputs, i.e. energy and raw material consumption and emissions to the air, water and land. However, it may be adequate to focus on only one area, e.g. energy consumption, if other areas are equal for the compared systems.

Life Cycle Impact Assessment

The life cycle impact assessment phase will be simplified by regarding the choice of environmental problem themes and issues and the calculation of theme scores and weighting factors.

One approach is to use impact indicators like for instance 'energy use'. Several simplified LCA method use such an approach (Leffland et al., 1997), (Wenzel et al., 1999) using indicators for energy related impacts, impacts related to chemicals and resource consumption.

Assessing Reliability

The aim of simplification in LCA is to derive results that are sufficiently reliable for the required purpose, while putting in less effort than in a detailed LCA study. In order to check that a simplified LCA achieves this, the final step in a simplified LCA needs to be the reliability assessment.

The reliability of a simplified LCA will depend on the same factors affecting the reliability of a detailed LCA. The factors can be briefly categorised as:

i) Data quality and relevance, which ensures that appropriate data with respect to time period, geography and process, are used. In addition to that, the data gabs have to be filled. This can only be done by expert judgement.

ii) Methodological choices. The overall reliability of the conclusions has to be related to the goal and scope of the LCA study. For the overall the choice of functional unit, system boundaries, goal definition, screening arguments are addressed.

iii) In simplified LCA, the data used may often be of lower quality/relevance than of a full LCA. One way to check the reliability of the final result is to identify the key data (those that most affect the final result) and then to check their level of uncertainty. This can be done using sensitivity analysis. This analysis is performed on selected parameters.

1.3 The simplification approach used in the study

The simplified LCA method used in the study was developed by Wenzel et al. (1999). The approach to simplification is:

i) to limit the scope of the study by using only very rough estimates for the life cycle stages of product manufacturing and transportation. The method guideline (Wenzel et al., 1999) justifies this and guides through how it is done,

ii) to limit the inventory to look at inputs and, thus, use inputs as indicators of outputs. This has been found to be adequate and often even better than to use data on measured outputs/emissions,

iii) to base the impact assessment on impact indicators in the categories: 1) materials consumption, 2) energy consumption, 3) chemicals consumption and 4) “other”. This has proven to be an operational way of covering relevant impact categories.

This approach saves a lot of time and effort and is sufficient for many applications. The difference between this simplified approach to the standard for detailed LCA’s (ISO, 1997) is illustrated in table 1.

Table 1. The components of a detailed LCA according to ISO 14040 compared to the used simplification method (Wenzel et al., 1999)

LCA (ISO 14040)	- *Simplified LCA (Wenzel et al., 1999)*
GOAL DEFINITION	- *Goal Definition*
- *Scope Definition* - Materials - Manufacture - Use - Disposal - Transport	- *Scope Definition* - Materials - (Manufacture) - Use - Disposal - (Transport)
Inventory Analysis - *Input data* - Output data	- *Inventory Analysis* - Input data
Impact Assessment - Classification - Characterisation - *(Normalisation)* - Valuation	**Impact Assessment** - Using aggregated environmental indicators
Interpretation	**Interpretation**
- *Decision*	- *Decision*

2. Life Cycle Assessment of water reuse scenarios in moulded pulp production

In pulp and paper industry, reuse of process water is in focus, and most companies strive to achieve a high degree of recycling without compromising product quality or working environment conditions. A high degree of recycling, however, improves conditions for microbial growth in the system, and to control the growth, companies most often use biocides. Other problems may follow a high degree of recycling, and the most commonly reported are:

i) Problems related to biocides.
ii) The concentration of salts giving rise to precipitations.
iii) Corrosion of equipment.

In the effort to seek environmental improvements, Hartmann look for options to avoid the use of biocides but still remain the same degree of water recycling or even increase this. One approach of achieving this is to remove the substrate of microbial growth instead of combating the growth. This could be done by an in-line biological treatment the plant. The biological processes may be aerobic or anaerobic, or a combination of these modes may be used.

2.1 Scenarios for water treatment and reuse

A number of scenarios using in-line aerobic or anaerobic treatment to remove the substrate for microbial growth in the back-water was studied. They can be implemented in the back water at different points, either close to the pulper or after the paper machine, see figure 1.

INVITED PRESENTATIONS

There was a wish to include anaerobic treatment, because it was intuitively believed to be potentially environmentally feasible due to the fact that energy (from methane) is *produced* during the COD removal as opposed to aerobic treatment *using* energy for the COD removal.

Initial modelling in the PC-tool WinGEMS from the company Pacific Simulation allowed an assessment of the steady-state conditions of the recycled water at various points of intervention of the treatment plant in-line in the system. The following key information was available:

- The water flow varies at the different points in the system. The dry matter concentration of the pulp is highest in the pulper (4%) and lowest down stream in the paper machine (1.3%). The water flow is, thus, highest just behind the paper machine. For the studied production volume (which is just part of the total production), the backwater flow at this point is around 200 m3/h.

- For the studied production volume, the COD load from the raw materials amounts to 24 kg/h of which around 50% is readily degradable in a biological treatment plant. The COD load of the added chemicals corresponds to around 12 kg/h of which 75% is judged to follow the product into the oven while 25% stays in the backwater. This COD is judged to be readily degradable. The load of readily degradable COD to the backwater is, thus, assessed to be around 12+3 equal to 15 kg/h in total.

- If a treatment plant is located to treat the total backwater flow and removes the readily degradable COD, it is, thus, evident that the steady-state COD concentration in the inlet of this plant is around 75 mg/l.

This modelling clearly shows that anaerobic treatment is not feasible at this point of intervention, the concentration of degradable COD is much too low. For an anaerobic plant to be attractive, the concentration of degradable COD should be at least five times higher, maybe even ten times higher. Moreover, aluminiumsulphate is added to the system, and the sulphate concentration is relatively high implying a high hydrogensulphide concentration in the gas.

The idea of segregating the system therefore arose, making a closed loop around the pulper, where the water flow is much smaller and where sulphate is not yet added. The release of COD to the water phase from the raw material was tested (Figueroa and Sanz, 2000) and found to be very quick. After just 10 minutes, all degradable COD was released. This would allow for segregating the system after buffer tank 1, filtering (and washing) the pulp at this point, and keeping the COD in a closed loop around the pulper at much higher concentrations – four to five times higher, and with only a small concentration of sulphate deriving from the raw material. If anaerobic treatment should be technically/economically feasible at all, it should be at this point of intervention. It might be necessary to treat the effluent from an anaerobic plant by an aerobic afterpolish in order to remove volatile fatty acids generated in the anaerobic plant. And it still might be necessary to have an aerobic treatment in the loop around the paper machine.

Therefore, a number of scenarios were modelled comprising a number of such combinations. One scenario without segregation of the system in two loops comprising, thus, aerobic treatment of the backwater in one system. Plus a number of scenarios with anaerobic treatment in a pulper loop and aerobic treatment in a paper machine loop as illustrated in figure 1. Moreover, the implications of by-passing part of the water and treating only part of it were modelled and included as scenarios.

In total, eight scenarios were assessed. It turned out, though, that the significant difference stood between anaerobic treatment and aerobic treatment in general, and the comparison is, therefore, shown here on four scenarios only.

2.2 Goal definition

The goal of the study was to compare alternative in-line biological water treatments to effectively remove the substrate for microbial growth in the process water and, thereby, avoid the use of biocides.

2.3 Scope definition

Only part of the total production volume at the company was studied, namely a production of 2500 kg/h of final product with a dry matter content of 95%. This is the overall service provided by the studied system, and this service should be provided unchanged by whatever solution is taken for the water treatment. Moreover, the service is specified to be provided for 25 years. The period of 25 years is selected, because it corresponds to the life time of the treatment plants.

In order to effectively remove the substrate for microbial growth in the system, the treatment plants would have to remove around 15-20 kg/h COD equivalent to around 3,300 – 4,400 tons COD per 25 years. This removal of COD from the process water corresponds to the daily COD addition with raw materials and chemicals and has been judged to be sufficient to avoid the use of biocides.

All candidates for a solution should provide this service, and should, moreover, be comparable on a number of other properties as well, see table 2.

Functional unit

Table 2 illustrates the qualitative and quantitative properties that the treatment plants used in the scenarios have to fulfil.

Table 2. Functional unit of the studied scenarios for water treatment and reuse

Qualitative properties	• Allow to operate the system without the use of biocides • Low manpower requirements for operation and maintenance • Not increase the amount of nutrients available for microbial growth in the overall system
Quantitative properties	• The removal of 15-20 kg/h COD continuously at the water conditions of the system
Duration	• 7 days a week for 25 years

The reason for specifying that the solutions should not give rise to an increase in available nutrients is, that nutrients, especially nitrogen, has been found to be limiting to the growth. A nutrient increase might, thus, counterweigh the COD removal to some extent.

Secondary services of in-line process water treatment plants
Besides providing the service described above, the aerobic and/or anaerobic plants in question will lead to the secondary services through the following by-products:

- Energy production from methane
- Sludge as compost and/or energy recovery source

A treatment plant would, thus, not only provide the service of water treatment for which it was intended, but also other useful services. The practical implication of the fact that these other services are provided would be, that alternative ways of providing these services would be substituted. In other words: if methane is produced and used, e.g. in Hartmann's own heat & power plant, which already runs on gas, natural gas would be substituted. And if biological sludge from the plant is being incinerated in a municipal waste- or sludge incineration plant from which energy is utilised (which is the case for such plants in Denmark), district heating and electricity produced by this sludge incineration will substitute conventional fuels for producing these utilities.

Of course, such substitutions caused by the secondary services imply environmental benefits, and it often turns out to be the most important issues in the study, because the flows related to these secondary services are relatively large. This turns out to be the case in this study as well, just consider the flow of 3,300 – 4,400 tons COD/25 years compared to the flow of materials for constructing the treatment plants. In an anaerobic plant, this flow of COD is either turned into gas or biomass (sludge) both giving rise to energy production in a subsequent incineration.

Another important flow being affected by the treatment plant is the final product:

- Removing COD from the process water of course implies that less COD will follow the product into the oven. This will lead to a slightly lighter product, as the COD is not contributing to the product's intended properties, wherefore the weight loss will not be compensated. As part of the product will be incinerated end-of-life in incinerators with energy utilisation, this will imply a loss of energy production at this point, which has to be supplied by conventional energy sources instead.

As the COD removal is specified in the functional unit, the implication of this will be the same for all solutions. But the significance of it will have an influence on the magnitude of the difference between the scenarios, and therefore it is included.

Impact categories
There is no difference in chemicals consumption between the scenarios. On the contrary, the functional unit implies the same impact on use of biocides from all scenarios and other chemicals are not judged to be affected. The main difference between the scenarios lies in the implications

on total energy consumption. No other impact categories are believed to be significantly different from one scenario to the other. The study is thus a comparison on energy, taken as primary energy consumption.

2.4 Inventory Analysis

Various data sources were used:

- Basically, the production data was gathered from the company, Hartmann, itself.
- Data on the treatment plants were taken from a number of sources having reported data on wastewater treatment in anaerobic and aerobic plants. The essential data are electricity consumption by the plants and sludge and methane production. The data quality of these data is believed to be quite good.
- As earlier described, the data for characterisation of process water are calculated by using simulation that is made in a program called WinGEMS from Pacific Simulation. The model is based on a steady state mass balance of water, suspended solids, sulphate and COD. Specifications are production rate, water flow constraints, sulphate addition during production, suspended solids concentrations and the COD release from the pulp with time.
- Data on materials production for the various plants and on disposal processes were taken from the EDIP LCA database (Frees, 1996). The data quality of these is good considering that only energy data is used in the study.

The mass and energy flows related to each scenario were compiled, see table 3. The table compares four scenarios: two scenarios in which the COD removal is done aerobically on the backwater after the paper machine (one with a by-pass), and two scenarios in which the COD removal is done anaerobically (in two different treatment plant types) in a closed pulper loop. In the two anaerobic scenarios, 20% of the COD is anticipated to be removed in an aerobic afterpolish.

Table 3. Reference flows per functional unit in two aerobic and two anaerobic scenarios - = none. UASB = Upflow Activated Sludge Blanket, ICR = Internal Circuit Reactor

Flows	Unit	Scenario			
		Aerobic		Anaerobic	
		Full	With by-pass	Full	
				UASB	ICR
MATERIALS					
Concrete	kg	7500	3750	21750	21750
Cast iron	kg	530	510	770	770
Steel	kg	1000	520	1230	1230
Stainless Steel	kg	2100	2100	2260	7550
Copper	kg	220	120	200	200
Aluminium	kg	-	110	190	190
PE	kg	2630	700	700	700
USE					
Electricity	MWh	10000	8000	2000	2000
Phosphorus	kg	25600	21800	14800	14800
Nitrogen	kg	128600	109200	73900	73900
Product COD incineration	kg	1700000	1700000	1700000	1700000
CREDIT					
Wastewater COD degradation	kg	-2800000	-2800000	-2800000	-2800000
Methane	kg	-	-	-854100	-854100
Sludge (dry matter)	kg	-1073100	-908850	-547500	-547500
DISPOSAL					
Shredding	kg	50	26	44	44
Manual Separation	kg	6000	4200	6800	11900
Incineration	kg	2370	640	640	640
Landfill	kg	6270	3250	17360	17470
REUSE/RECYCLE					
Remelting					
Stainless steel	kg	2060	2060	2210	7400
Al/Silicon	kg	-	-	-	-
Copper	kg	50	26	44	44
Steel	kg	1530	1520	3870	3870
Concrete	kg	-	-	-	-
CREDIT					
Stainless Steel	kg	-2060	-2060	-2210	-7400
Al/Si	kg	-	-	-	-
Copper	kg	-50	-26	-44	-44
Steel	kg	-900	-470	-1100	-1100
PE incin. (energy credit)	kg	-2370	-640	-640	-640
Concrete	kg	-	-	-	-

Materials

As is evident, the anaerobic scenarios requires more materials that the aerobic, because the needed hydraulic retention time in the anaerobic reactor is much higher than in the aerobic reactor. This implies a material consumption of the anaerobic scenarios of around twice the amount of the aerobic scenarios – equal to around 14 tons – primarily in concrete and steel.

Manufacture
No significant differences are believed to lie in the manufacture of the plant, compared to materials consumption, use and disposal of the plant, and the manufacturing stage is not included at all.

Use
Data on electricity consumption of an aerobic biofilter in another aplication is known to be around 2.5 kWh per kg COD removed, and this figure is used here. As seen, it amounts to 10,000 MWh for the full aerobic scenario compared to 2000 MWh for the anaerobic scenarios, being the electricity used for aeration in the aerobic afterpolish of 20% of the COD.

Nitrogen and phosphorus addition to the water just prior to the plants are needed for optimal COD removal, and this can be done without increasing nutrient content of the effluent of the plants as the nutrients are fully taken up by the biomass of the plants. Evidently, the aerobic scenarios need more nutrients than the anaerobic ones, because of the higher sludge production of the aerobic plants.

In today’s steady-state situation, COD in the circulating process water is around 3000 mg/l. Moreover, around 40% of the water leave the system through the ovens and the rest via the wastewater effluent. This implies that 40% of the COD follows the product, equivalent to around 1700 tons per 25 years. As a conservative estimate, this is taken as being fully incinerated in order to see the significance of this. The flow is equal for all scenarios, but is included because it is altered compared to today’s reference and in order to see the significance of it compared to the differences between the scenarios.

The rest of the COD leaves the system via the wastewater, where it is first let to Hartmann’s own wastewater plant and subsequently to the municipal plant further downstream. In these plants, electricity is used to remove the COD. This flow is, of course, also equal for all scenarios, because the COD removal is specified in the functional unit, but it is included for the same reasons as above.

Methane production is of course only present in the anaerobic scenarios, and here in an amount of around 850 tons per 25 years equivalent to around 1.2 mill. m3. Sludge production is highest for the aerobic scenarios, judged to be twice as high (remember the 20% aerobic COD removal in the anaerobic scenario), equivalent to around 1000 tons of sludge dry matter per 25 years.

Disposal
On disposal, concrete will be deposited, metals primarily recycled and plastic incinerated – as seen from table 3.

Most significant flows
As evident from table 3, already at this Inventory Analysis phase of the LCA, the flows of the operation of the wastewater treatment plants are seen to be the significant flows. The other life stages of the plants seem to be of no significance to the total burdens from the scenarios. The key

is the fate of the COD in the scenarios, and the energy flows this fate gives rise to. This is subsequently assessed in the impact assessment phase.

2.4 Impact Assessment

Data on energy consumption of the materials, energy efficiency of electricity production, energy utilisation in waste- and sludge incinerators etc. has been available (Frees, 1996), (Wenzel et al., 1999), and the mass-and energy flows per functional unit as presented in table 3 have been translated into consumption of primary energy. Primary energy is the energy content of the resulting fuels entering the system, when all flows are followed to the initial extraction of raw materials and fuels from ground.

The primary energy flows of the four compared scenarios are shown in table 4.

Tabel 4. Primary energy flows per functional unit in two aerobic and two anaerobic scenarios
- = none. UASB = Upflow Activated Sludge Blanket, ICR = Internal Circuit Reactor
? = no data available

Flows	Unit	Scenario			
		Aerobic		Anaerobic	
		Full	By-pass	Full	
				UASB	ICR
MATERIALS					
Concrete	MJ	15,150	7,496	43,500	43,500
Cast iron	MJ	30,475	29,440	44,160	44,160
Steel	MJ	35,028	18,284	43,050	43,050
Stainless Steel	MJ	181,040	168,080	180,720	604,320
Copper	MJ	20,000	11,000	18,000	18,000
Aluminium	MJ	-	19,000	32,000	32,000
PE	MJ	210,000	56,000	56,000	56,000
USE					
Electricity	MJ	36,000,000	28,800,000	7,200,000	7,200,000
Phosphorus	MJ	?	?	?	?
Nitrogen	MJ	?	?	?	?
Product COD incineration	MJ	30,600,000	30,600,000	30,600,000	30,600,000
CREDIT					
Wastewater COD degradation	MJ	-25,200,000	-19,000,000	-25,200,000	-25,200,000
Methane	MJ	-	-	-50,400,000	-50,400,000
Sludge	MJ	-10,731,000	-9,088,500	-5,475,000	-5,475000
DISPOSAL					
REUSE/RECYCLE					
Remelting					
Stainless steel	MJ	60,000	60,000	66,000	222,000
Copper	MJ	2,500	1,300	2,200	2,200
Steel	MJ	23,000	23,000	58,000	58,000
CREDIT					
Stainless Steel	MJ	-60,000	-60,000	-66,000	-22,000
Copper	MJ	-4,500	-2,300	-4,000	-4,000
Steel	MJ	-900	-470	-1,107	-1,106
PE (incineration)	MJ	-71,000	-19,000	-19,000	-19,000
å LIFE CYCLE	MJ	31,000,000	31,000,000	-43,000,000	-42,000,000

2.5 Interpretation

The significance of the use stage of the plants is now fully evident, and it is seen that the difference between the aerobic and the anaerobic scenarios is quite significant as well. A magnitude of 74,000,000 MJ is equivalent to almost 2000 tons of oil. In monetary terms, this amounts to around 2.2 mill DKK or around 0.3 mill US$ with the Danish oil-price of 1,1

DKK/kg of fuel oil (0.14 US$/kg). Per years, this is a quite low economic difference – around 12,000 US$/year.

Hartmann sees around the same difference, namely the difference between electricity consumption of the plant and methane production, and this amounts to around 80,000,000 MJ/25 years, the yearly difference on operation costs, thus, being around the 12,000 US$/year.

It is, therefore, clear that the anaerobic plant should not be much more expensive than an aerobic one, if economy is decisive. Moreover, an aerobic plant is less troublesome and time consuming to run and gives less odour problems in the factory. Technical criteria are, therefore, in favour of the aerobic plant.

References

Christiansen K (ed.) (1999): Simplifying LCA – Just a Cut? SETAC Europe Working Group in Simplification of LCA, 1999.

Wenzel H, N Caspersen and A Schmidt (1999): Life Cycle Check – A Guide. Institute for Product Development, 1999 (In Danish). An English version of 2000 exists.

Leffland K and H Kærgaard (1997): Comparing Environmental Impact Data on Cleaner Technologies. European Environment Agency, Technical report, no. 1, December 1997.

Figueroa M C and D Sanz (2000): Laboratory Scale Characterisation and Simulation of Pulp and Process Water of Moulded Pulp Production. Identifying Options for Preventing Growth of Micro-organisms by Removing their Substrate. Master Thesis, Technical University of Denmark, IPT-098-00.

Frees N and Pedersen MA (1996): EDIP Unit Process Database. Ministry of Environment and Energy, Danish Environmental Protection Agency. Copenhagen 1996. ISBN 87-7810-547-1

International Organisation for Standardisation, ISO (2000): Environmental management – Life cycle assessment – Principles and framework. International standard ISO14040: 1997 (E).

POTENTIAL AND FRAME PROGRAME IMPLEMENTATION OF CLEANER PRODUCTION IN THE ARMY OF THE CZECH REPUBLIC

Frantisek BOZEK*
Jan _TEJFA+
Ales KOMAR*
Karel DUSATKO*

* Military University, Faculty of State Defence Economy, Vyskov
+ Czech Cleaner Production Centrum, Prague

The transformation of the Army of the Czech Republic which is in progress in connection with significant international-political changes, out of which joining the NATO structures is undoubtedly dominant, brings a lot of tasks which must be solved promptly. In relation to the environment protection, it must be admitted, the Army adopts the legislation traditionally, nevertheless, from the viewpoint of active approach to environmental problems there are still many reserves. Namely, there are qualitatively new instruments, the application of which can make using resources significantly more effective and can reduce the impact of training and peacetime life of troops on the environment in economically effective terms. Undoubtedly, the implementation of environmental management systems, energy audit performance, risk assessment, the application of Life Cycle Assessment method and, last but not least, the Cleaner Production method [1].

The mentioned issues are taken into account accordingly on national levels of developed countries as well, which, namely in the Czech Republic, is demonstrated by the acceptance of the Government Decree concerning the National Programme of Cleaner Production which the defence sector belongs to. [2].

The interest of the armies of developed countries in the cleaner production implementation is not accidental. It results from the high potential for the cleaner production in the defence sector. The origin of the potential is affected by the variety of army´s tasks within the framework of fulfilling its mission with regard to the society, consequently the extensive spectrum of activities and materials used. The cleaner production potential in the defence sector must be taken as the possibility of reducing the production of waste and pollution by the more effective use of inputs and at the same time reducing material and energy costs while the existing quality of training and all functions of the armed forces are preserved.

From the viewpoint of the analysis concerning the possibilities of applying cleaner production it is necessary to divide the defence sector into individual sub-areas. In our opinion the following classification is optimal:

a) Material management.
b) Operation, maintenance and repairs of equipment.
c) Building resources
d) Training.

It has been claimed that the quantity of material classes used in the army is considerable and very heterogeneous by its character. They can be divided based on various aspects. However, concerning the cleaner production their division will be effective pursuant to the time durability:

a) Materials, the consumption of which is limited by time and which must be disposed after a certain time if they are not used. This class includes e.g. major part of ammunition, decontamination liquids, foodstuffs, most of medical and veterinary material, medicaments etc.

b) Materials, the use of which is limited exclusively by the development of new types and procedures and are substituted owing to the modernisation (rearmament). For example, armament, particular kinds of engineer, chemical, signal and building material, electronic systems etc. belong to this class.

c) Other material which is usually characterised as consumption material with undefined durability, such as for example some kinds of personal use material, cleansing articles etc.

In the sphere of the **material management** the high potential is expected, especially in connection with organisational measures which will certainly allow to reach the fast eco-economic effect without expending higher investments. The potential lies mainly in the field of communication among individual military units and institutions or the civilian sector so that materials can be handed over, exchanged or sold before the durability date expires. The measures presume the provision of developed material logistics, partially expending investments to build necessary information networks. Logistics is related to ordering, purchasing, accounting, storing, and consuming materials. Certain possibilities of the mentioned type can be also found with materials having the lapse term of persistence (certain kinds of chemical, engineer and other materials). These materials have the character of relatively clean substances. Their processing in some of appropriate chemical industry branches is possible even if changes in the chemical composition caused by time and storage conditions can prevent from using some substances. Moreover, the type of improvement already presented is not included in the cleaner production. The potential can be also found in the method of rate and composition prescription of emergency rations, namely concerning the ACR membership in the NATO structures and the possibilities resulting from this [3].

Regarding the **operation, maintenance and repairs of equipment,** the significant potential can be expected here as well. In the sphere of logistics it is mainly a matter of transport exploitation, which in the final consequence could lead to the reduction of kilometres covered and thus the reduction of fuel consumption. The assessment of appropriate use concerning existing kinds of tyres and their possible change would probably require higher investment costs with the longer pay-off period. Logistics relating to fuel, spare parts, preventive maintenance and equipment preservation would certainly detect the other reserves. These, undoubtedly, can be found when refuelling, changing oils, handling them etc. The method of washing equipment on conveyor washes has a specific position in this group where, for example, using the circulation of rinsing water and continuous water cleaning can affect the water requirement markedly and especially the degree of surface moisture pollution. By analogy, as in the previous class of materials, the interesting potential exists here as well, namely in the rate prescription of emergency rations.

Problems of **building resources** are parallel in the civilian sector. The potential can be found especially in the reduction of the energy demand factor of buildings which are heated. These are often old, designed in the past when only the irrelevant attention was paid to thermal insulating parameters of constructions. The heat distribution usually is in emergency conditions and does not allow temperature control.

Concerning the financial aspect the highest potential can be found quite certainly in the area of **training** which is often carried out using mock-ups and simulators. Higher quality of training is provided, costs are reduced significantly, safety is higher, the effectiveness of using armament is increased, operational research is exploited and at the same time ill-effects on the environment are eliminated. Simulators and simulating activities represent the most effective approach concerning the training of armies when trends of sustainable development are integrated at present. [4]. Nowadays, up to 65% of training using simulations is implemented in NATO armies and the mentioned percentage is going to increase in the future. Moreover, consumption logistics plays a significant role in the system of classical training, which represents another potential.

Based on the above-mentioned analysis it is obvious that in the defence sector there is an enormous potential of cleaner production in agreement with theoretical considerations. In the next period of time it will be necessary to find appropriate forms of possible implementation and to define possible obstacles which could affect the implementation of the mentioned process in a negative way. The mentioned obstacles will have to be eliminated on a large scale.

We consider the most significant obstacles to be:

a) **Classified matters security** [5]. Removing this obstacle can be carried out by the training of selected army personnel. They will participate in developing demonstrational projects while civilian experts are supposed to provide general methodological instructions.

b) **Minimal interest in co-operation on the level of bases**, e.g. input-output analyses. This obstacle can be partially eliminated by the appropriate choice of facilities, by explaining tasks in detail and training personnel involved. It will be necessary to explain which effects the project will bring and further that it is not a matter of revision which possible sanctions will result from.

c) **Low motivation to achieve savings**. It is necessary to find a suitable mechanism to motivate entire units, personnel of military facilities. There are several opportunities the most important of which, we believe, are the following:

- perfect management structure inside the army which will be able to use to manage cleaner production projects
- further improvement of the accounting system of all materials, their consumption, using equipment etc.

The goals of cleaner production implementation are to enhance the exploitation of resources in the military sector and to reduce environmental impacts in economically effective terms. To achieve these goals we propose to train selected personnel from the army in the first phase. These should be regional ecologists and ecologists or experts having cumulated duties of an ecologist in selected units and military facilities. Also selected experts from military universities possessing appropriate specialised orientation. Some of them are expected to start developing demonstrational projects under the leadership of experienced consultants from the Cleaner Production Centre. These projects should be chosen specifically to prevent the leak of classified matters. We recommend to involve for example military kitchens, laundries, steamboiler plants, equipment to repair personal use material etc. The second part of participants should manage the demonstrational projects in selected bases where they are going to work with classified matters. The co-operators from the civilian organisation will not participate directly. They will provide methodological advice without any familiarisation with concrete military data.

The measures where there are no investments should be prioritised, namely of organisational character which will be found in the course of the project development. By the application of these projects financial means should be gained for the gradual implementation of the capital-intensive measures which should have the rate of return shorter than three years. In this way further means should be achieved, but relevantly higher which should later serve to cover the most capital-intensive project.

Costs to execute demonstrational projects should not exceed a certain value – in our opinion – 5 million crowns related to our army including extra payments for army workers who will be involved in the project development.

In conclusion it is necessary to remark, that Cleaner Production is one of the significant proactive tools which is used by civilian enterprises to reduce of quantity of produced waste and production effectiveness increasing. Its implementation can lead to relevant improvement environmental safety in the military sector.

Literature:

1. BO_EK, F. a URBANOVÁ, R. Dangerous Waste Handling in the Army of the Czech Republic and possibilities of its making more effective. In Proceedings of International Conference CATE´97, Brno: Fairs and Exhibitions Venture, 7th May 1997, p. 49-58.

2. Government Decree concerning the National Programme of Cleaner Production No. 165/2000 Coll. Prague, 2000. 1 p.

3. The NATO Handbook. Brussels: Office of Information and Press, 1998. 400 p.

4. NATO/CCMS Pilot Study. Use of Simulators as a Means of Reducing Environmental Impacts caused by Military Activities. Report No. 210, November 1995. 66 s.

5. Law No. 148/98, Collection of Laws, on Classified Matters Security.

RETURN TO CONTENTS PAGE